Challenges in industrial point sensing- NDIR

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Alphasense

- A private company in the UK, located near Stansted airport, between London and Cambridge
- Established January 1997
- We manufacture gas sensors

- **Market:** Industrial safety & air quality sensors
- **Research investment**: >£2M/ annum
- **Staff:** 75+

Our Technologies

Electrochems

MOXs

NDIRs

Pellistors

PIDs

OPCs

Beer Lambert Law (II)

In 1852, Beer showed that the absorption coefficient for monochromatic light is proportional to the concentration of the absorber and thus led to the Beer Lambert Law:

$$\log(I/I_0) = -\varepsilon c l$$

where:

I_o is the incident light power

c is the molar gas concentration

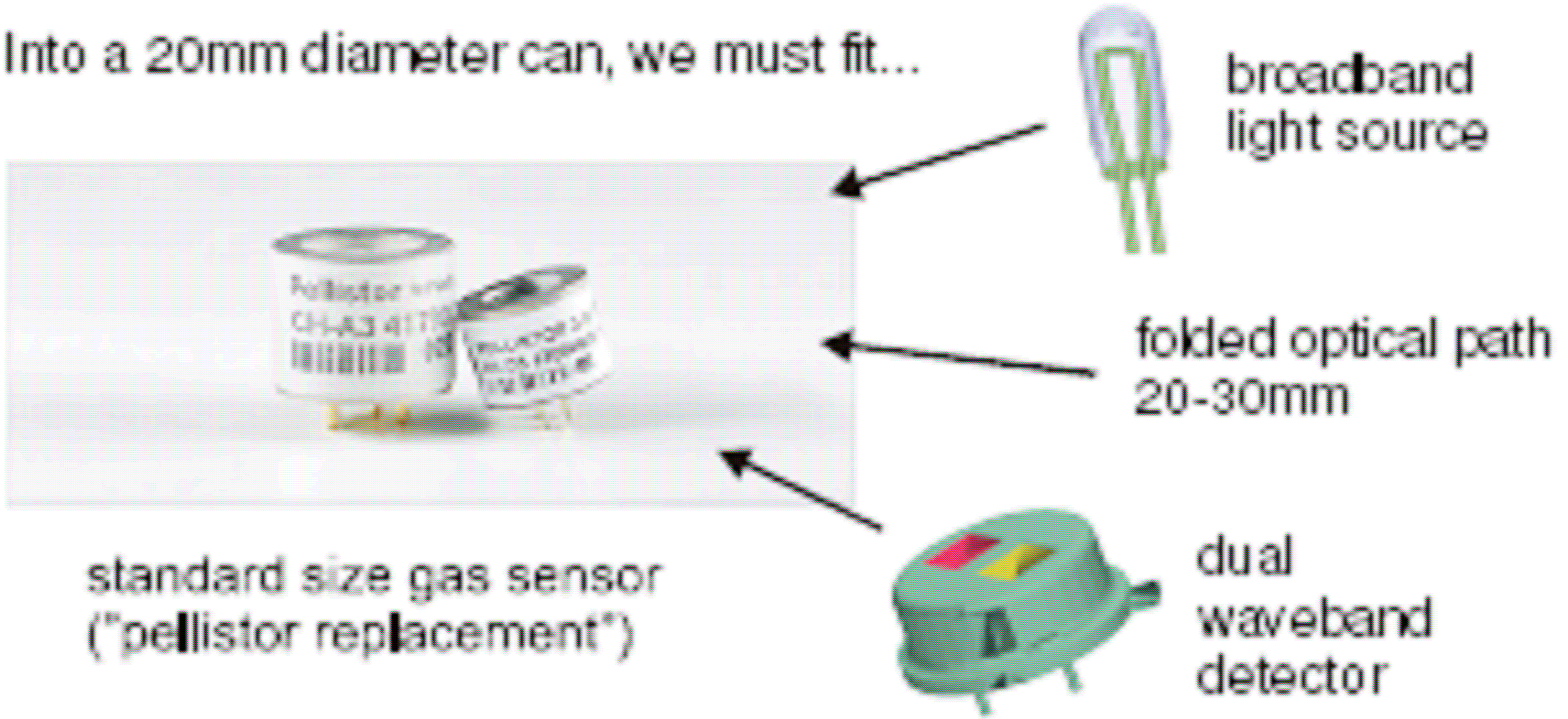
l is the pathlength and

ε is the molar absorption coefficient

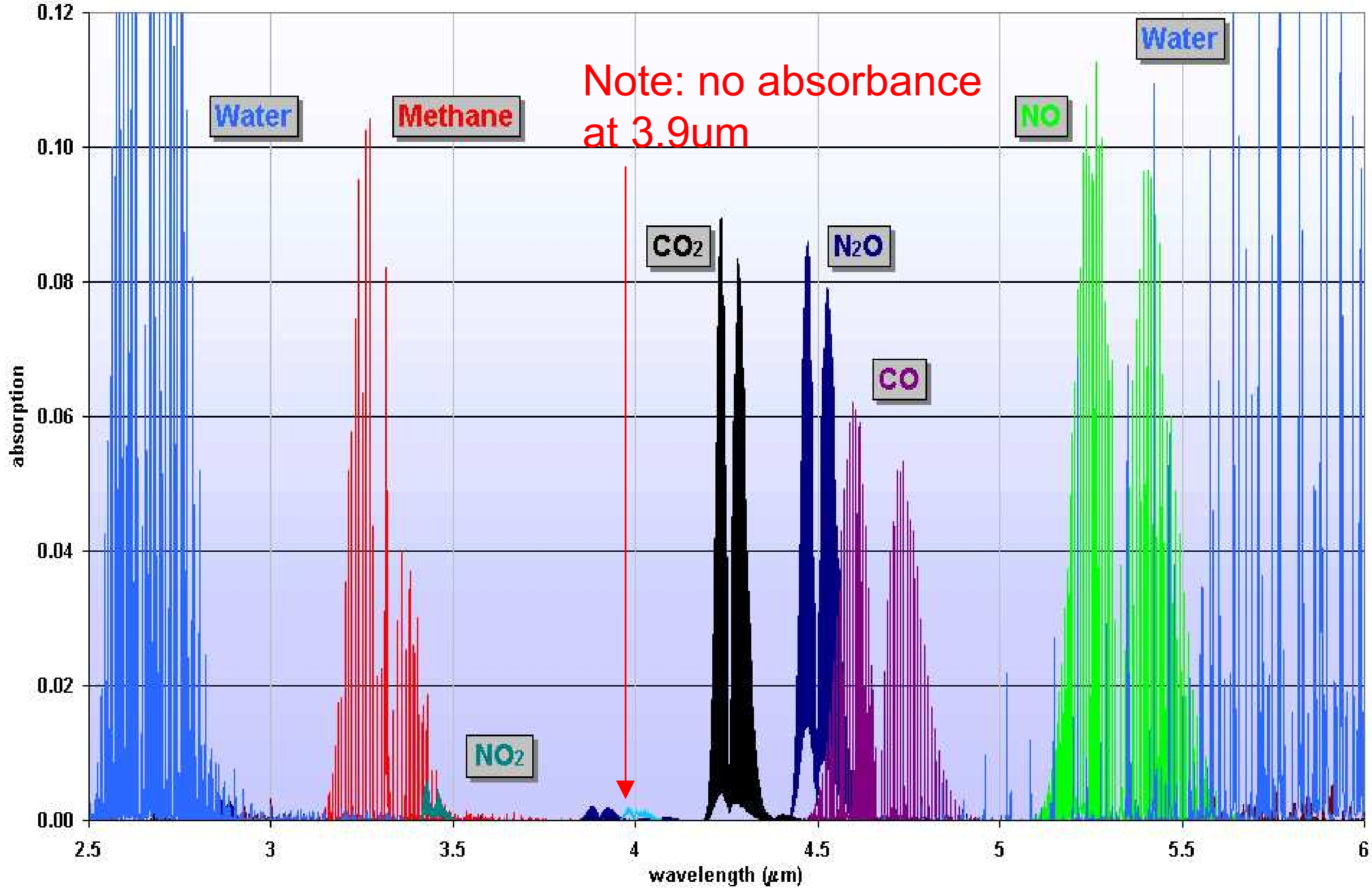
How does NDIR work?

Non-Dispersive Infrared detection integrates the Beer-Lambert Law over a band of wavelengths.

The trick is to fit it into a small sensor.



Many gases have absorption bands in the mid-IR



What gases to measure?

Methane, hydrocarbons

Safety (0-5%, 0-100%)

Leaks (0-500 ppm)

CO_2

IAQ/ ventilation control (0-2000 ppm)

Safety (0-5%)

Combustion control (0-18%)

Process control- intensive growing, bioreactors (0-100%)

Methane and CO_2 are the two most important greenhouse gases (GHGs)

Others

Ammonia -agricultural, refrigeration (0-100 ppm)

Aromatics -health and safety (0-5 ppm)

Water -semiconductor processing (0-100 ppm)

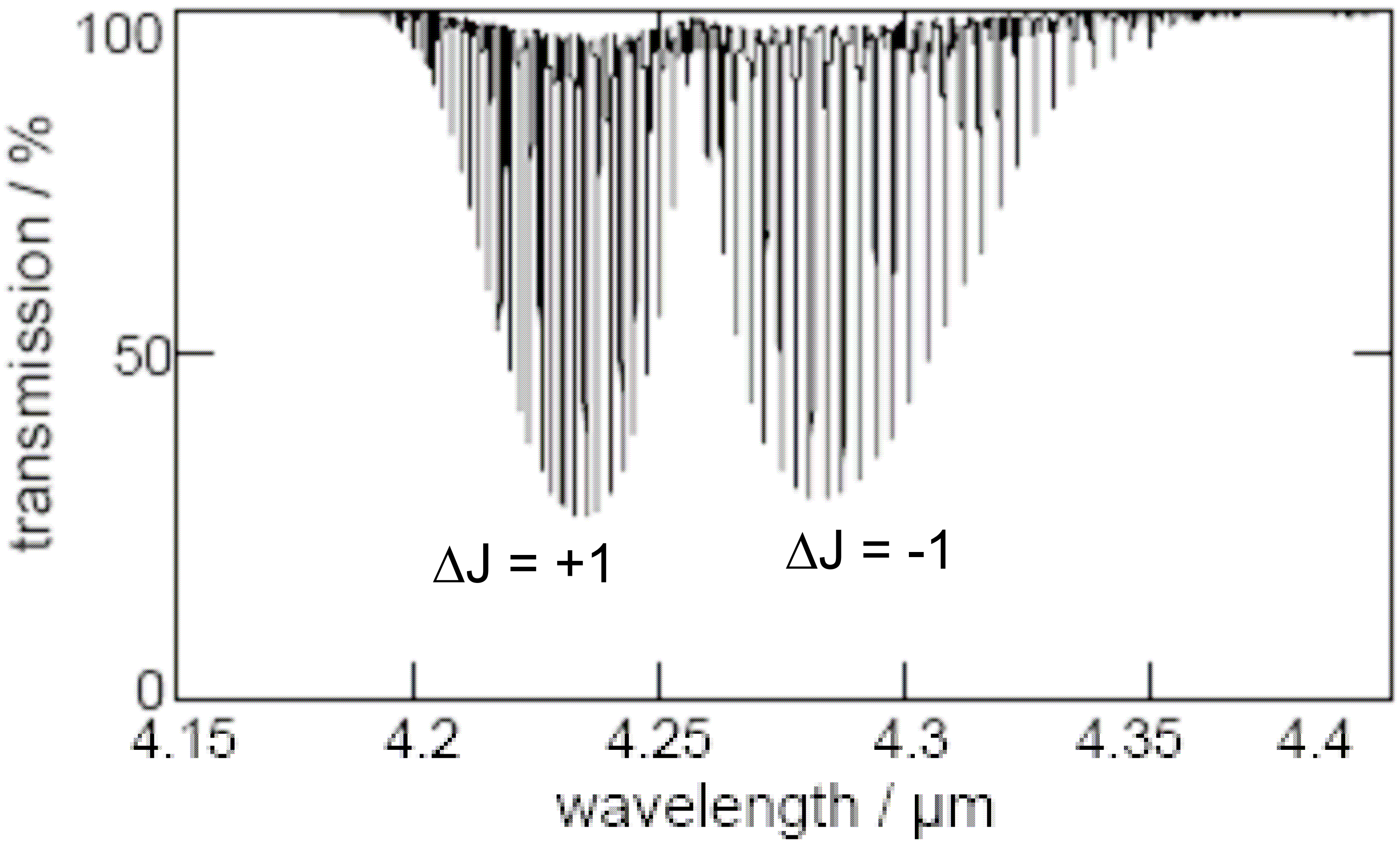
Applying the Beer Lambert Law to CO_2

- We want to measure the CO_2 band between 4.2 and 4.4 micrometers.

- We require a reference channel at 3.9 micrometers to correct for source and detector drift, and temperature dependence.

What shape is the CO_2 band?

Carbon dioxide absorption, calculated from HITRAN with 32 mm pathlength at 0.1% CO_2 concentration



We now have a summation of Beer-Lambert Law for each line in the absorption band:

$$I = \sum I_0 e^{-\varepsilon c l}\Big|_{\lambda}$$

ε is not a constant, it varies for each peak in the band

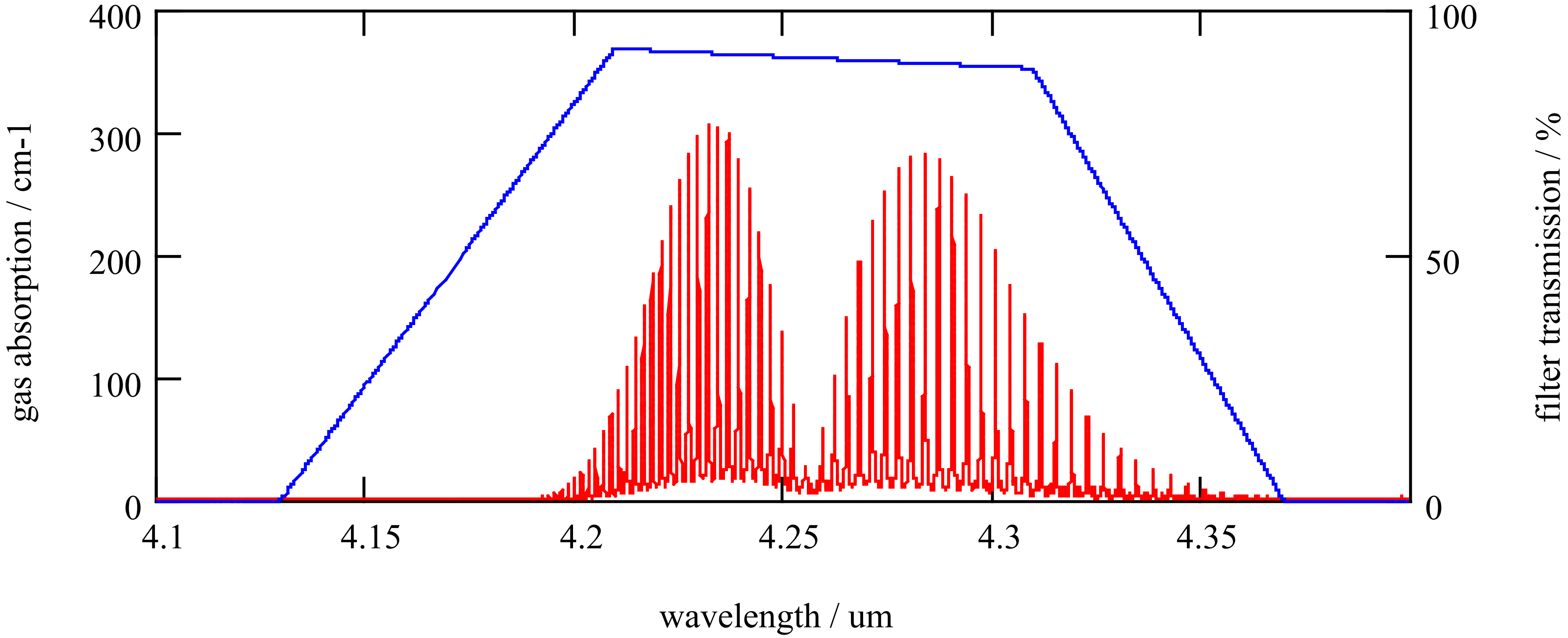
Let us now look at the choice of filter.

Filter selection is critical to minimise non-Beer Lambert performance

- Most NDIR gas sensors use either pyroelectric or thermopile dual detectors. Single low cost detectors save cost; and more expensive but better performance photovoltaic or photoconductive detectors are available, with much better D*, but at much greater cost.

- Manufacturers of NDIR detectors obtain filters from different suppliers with different performance. Caveat Emptor.

Ideally, the detector filter should match the absorption band-
this is difficult over the entire temperature range and incident angle onto the filter.



Choosing the right filter- IR notch filters are not ideal:

– Filter bandwidth should match the absorbance band.

– Filter centre frequency should be in the middle of the absorbance band.

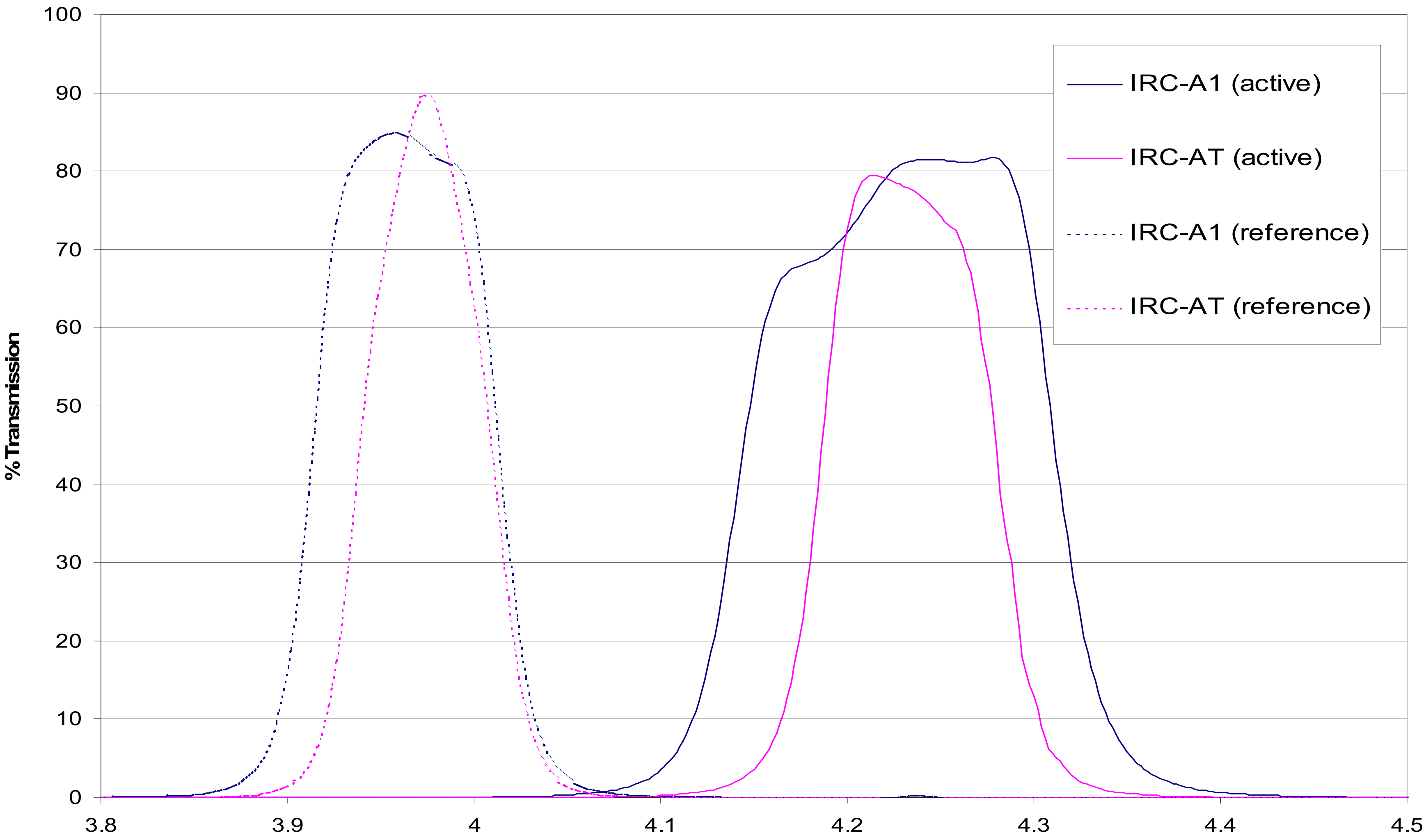
– “Top hat” performance is a goal.

– Non 90° incident rays should not see a shifted filter wavelength.

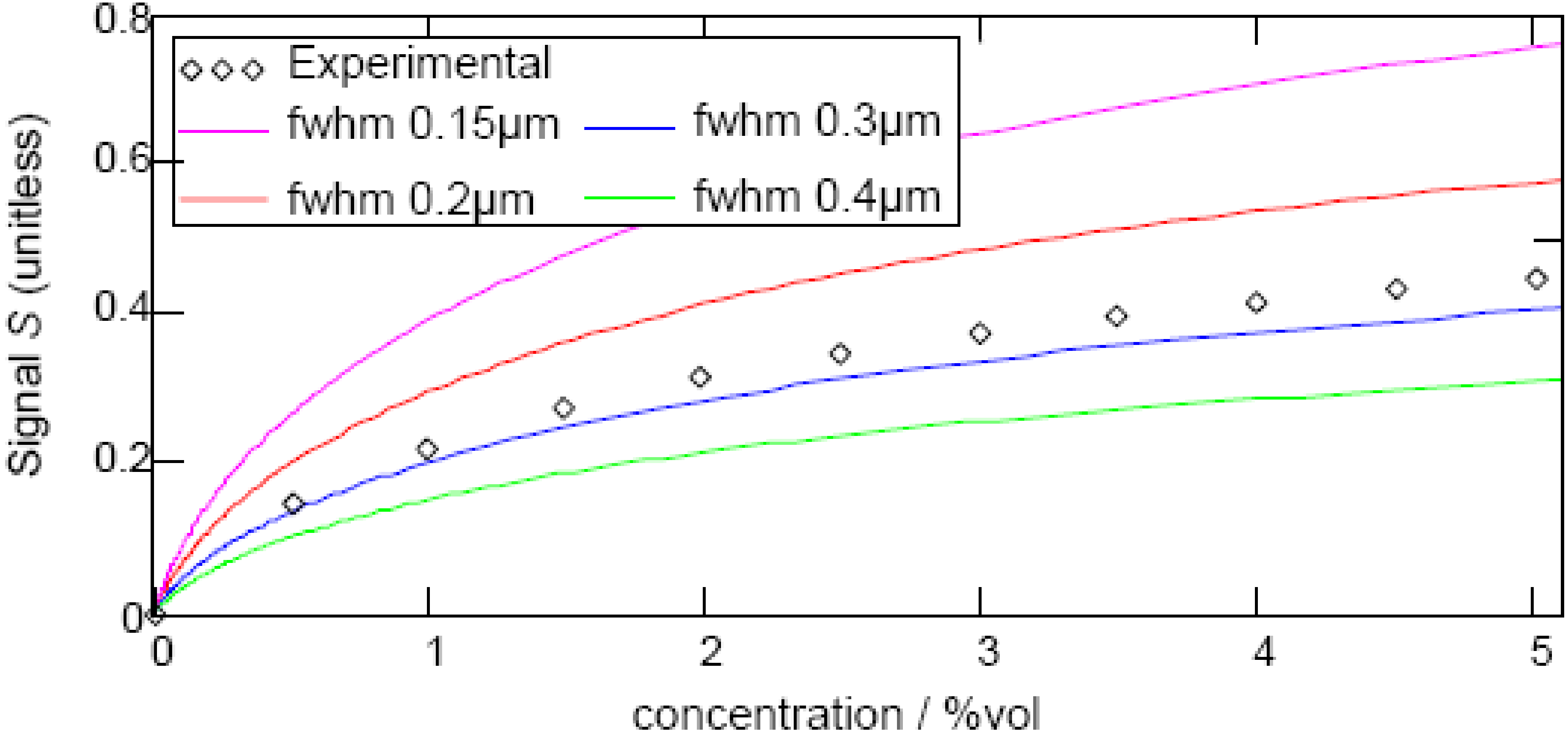
– Temperature shift of the filter should be minimised.

Notch filters have different centre frequencies and widths. This affects the amount of non-absorbing light on the detector.

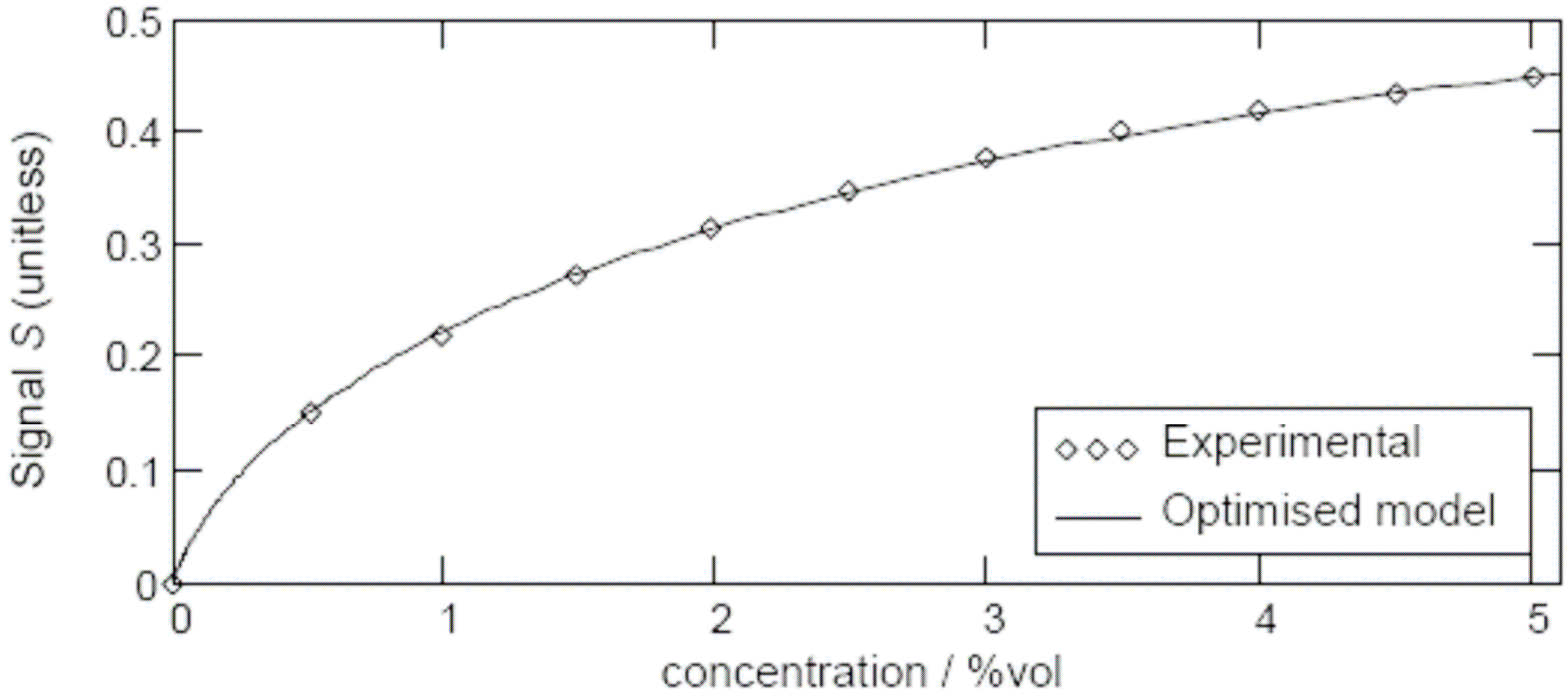
Below are two detector filters we use



Filter bandwidth affects the signal Beer-Lambert linearity because of the non-absorbing radiation.



Good agreement when experimentally fitted with "top hat" filter with centre wavelength of 4.23um and fwhm of 0.274um.



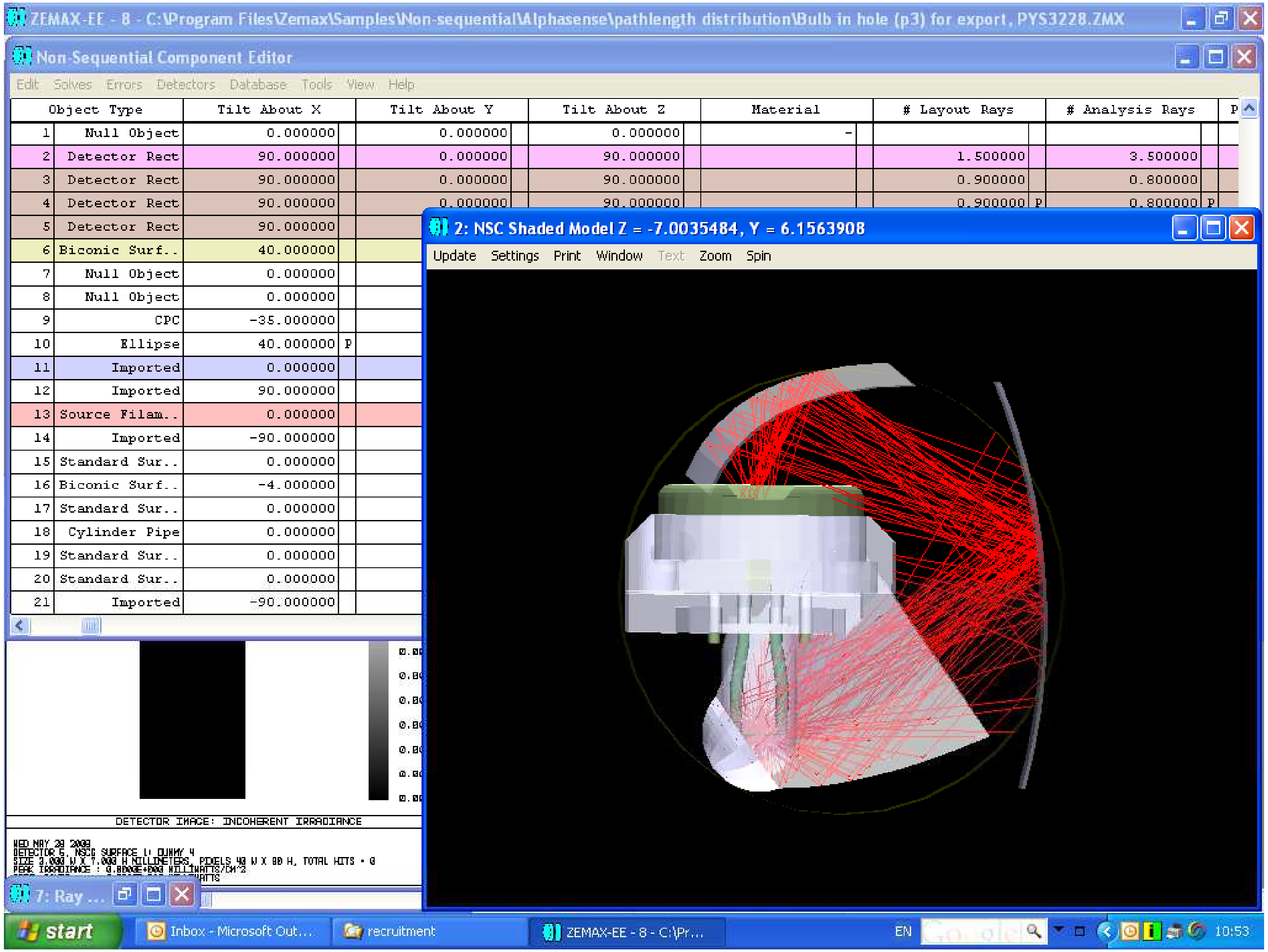
Problems of pathlength

Beer Lambert Law assumes one pathlength. This is not achievable in a small optical system:

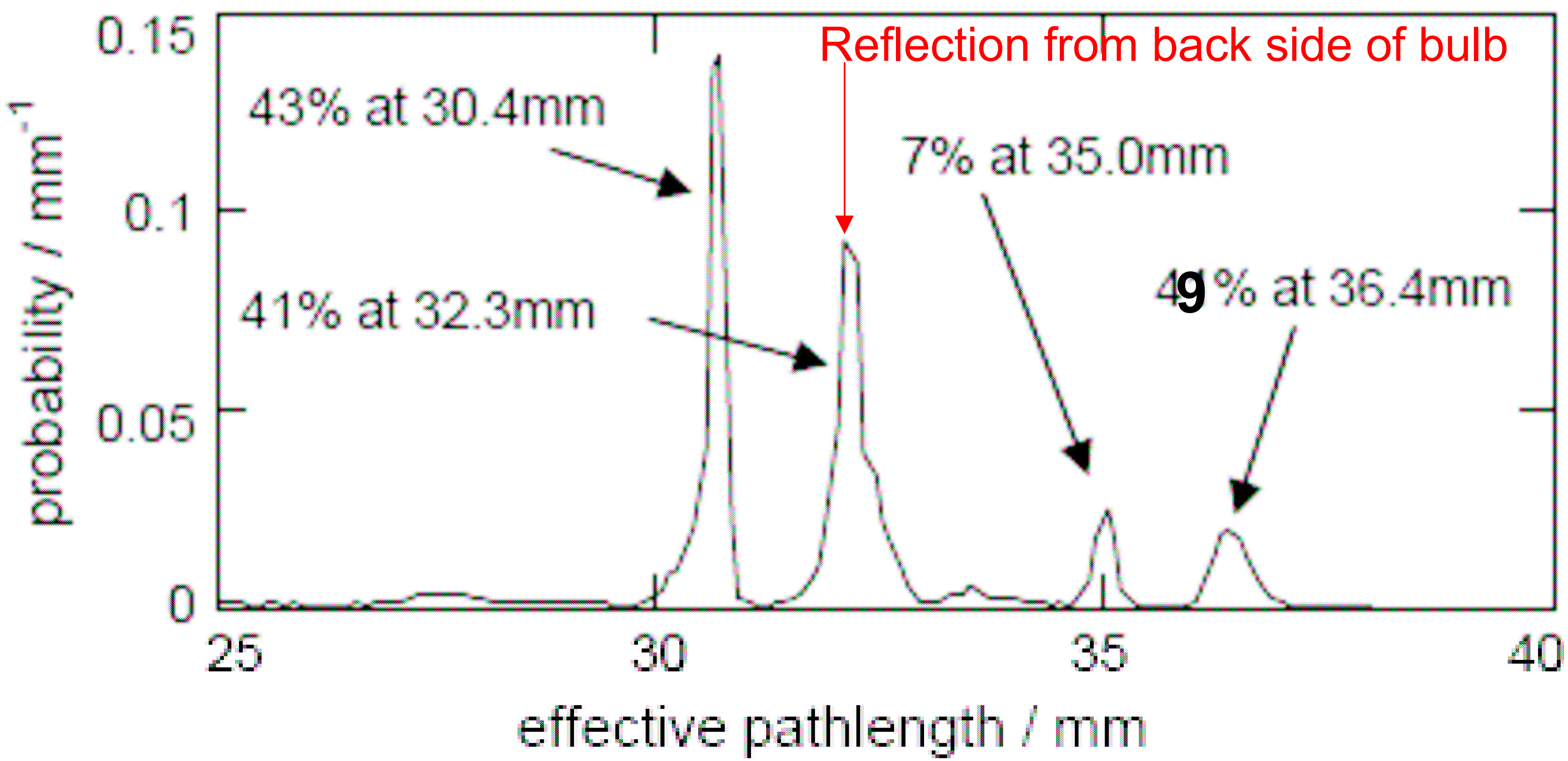
- The finite dimensions of the source (tungsten coil) spread the pathlength.

- Optical geometry controls pathlength distribution:
  - scattering between two plates (integrating sphere-almost)
  - simple waveguide
  - focused parabola/ mirror (our design)

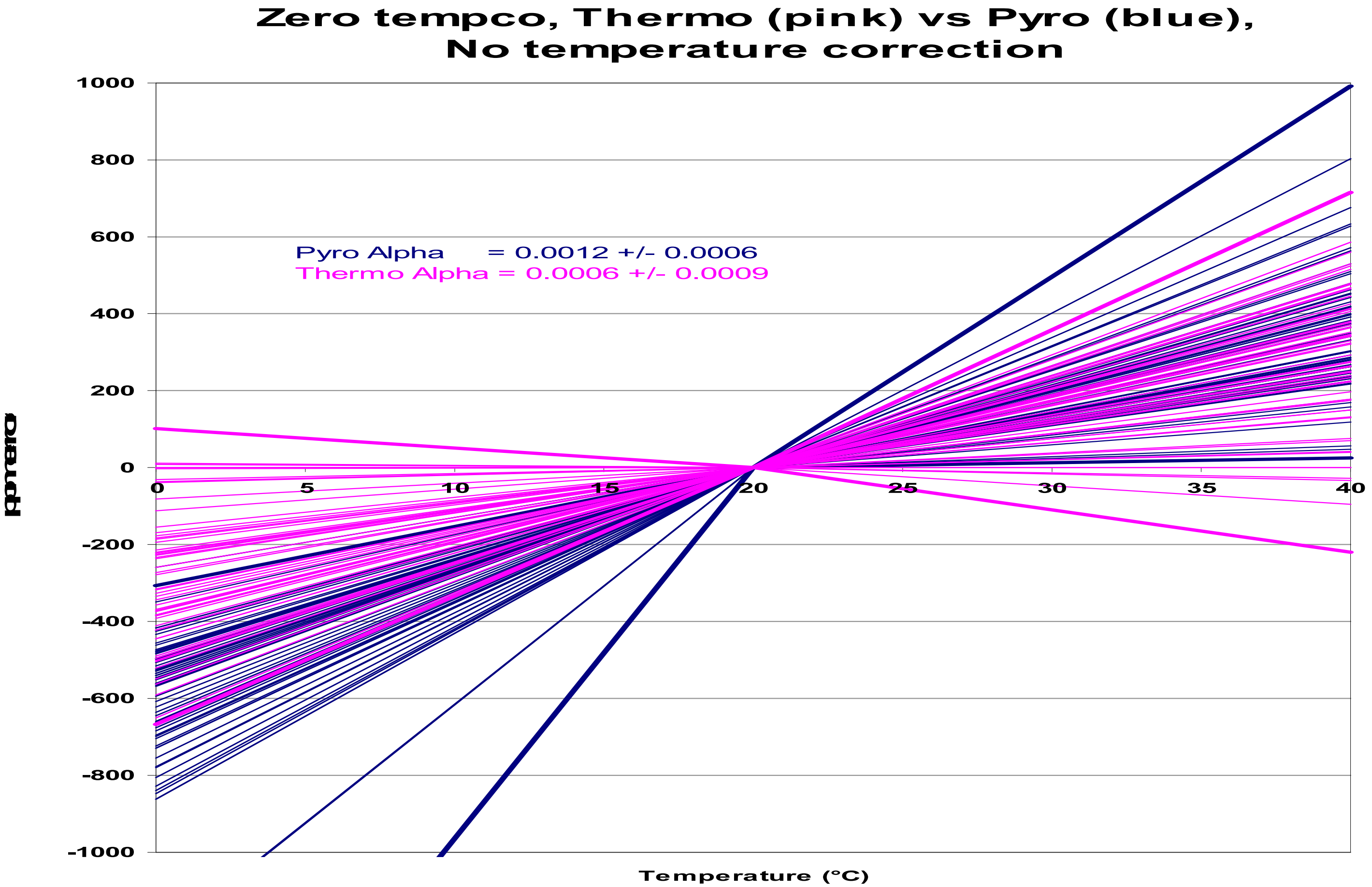
Model the optics with Zeemax:



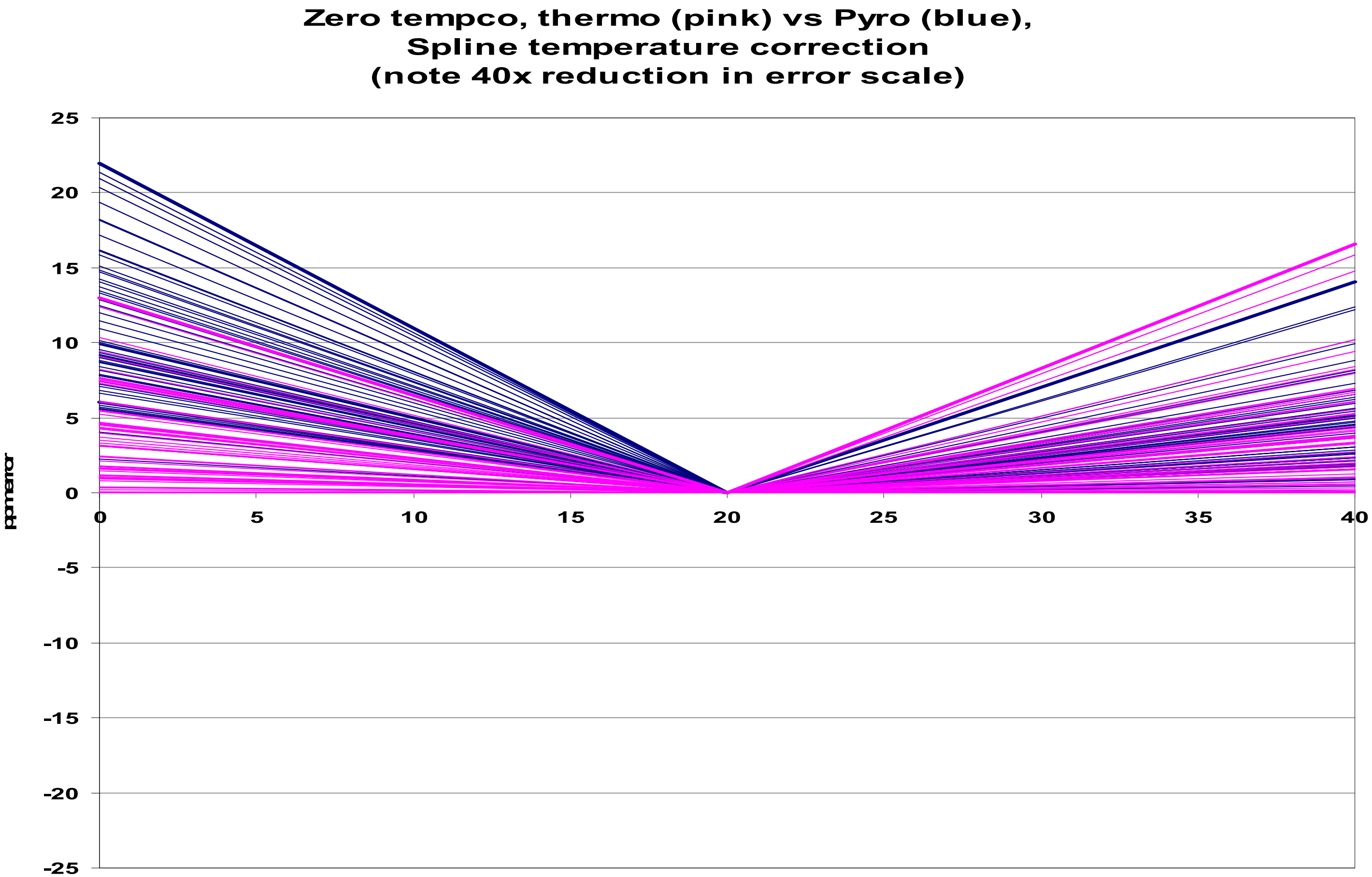
Determine the probability distribution function of effective pathlength



Detector zeros shift with temperature



A universal linear spline fit corrects zero to an acceptable error



Conclusions

- Beer Lambert Law assumes monochromatic light with a single pathlength.
- NDIR cells have a distribution of pathlengths and measure over a band of wavelengths.
- Detector filters play a crucial role in performance because of filter bandwidth and field of view (FOV) errors.
- Careful optical path design minimises FOV and pathlength distribution errors.
- Lower concentrations follow Beer Lambert closest because of reduced analyte shadowing.
- As the cell approaches Beer Lambert performance, the cell can use universal calibration constants with little error.

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